

Changes in Machining Students' Learning Outcomes Following CAM Design and Simulation Video Tutorials

¹Prido Subekhi, ²Saifuddin Karim, ³Marsono

^{1,2,3} Department of Mechanical and Industrial Engineering, Universitas Negeri Malang

*Corresponding Author: saifuddin.karim.ft@um.ac.id

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ABSTRACT

Computer-Aided Manufacturing (CAM) learning in vocational high schools still relied heavily on oral explanations and written materials, although CAM content was procedural, visual, and required step-by-step demonstrations. This study examined changes in the learning outcomes of Grade XI Machining Engineering students at SMK Negeri 1 Singosari before and after learning through CAM design and simulation video tutorials. A quantitative pre-experimental one-group pretest-posttest design involved 34 students selected through total sampling. The intervention was conducted over five meetings using video tutorials covering design creation, tool and material selection, machining parameter settings, toolpath generation, simulation, and CAM process verification. The instruments consisted of a practical test, an analytical assessment rubric, and a Likert-scale questionnaire. Content validity was assessed through expert judgment using Aiken's V, with a mean value of 0.948. Data were analyzed using descriptive statistics, the Shapiro-Wilk test, a paired-samples t-test, Cohen's d_z , and normalized gain. The mean score increased from 57.09 to 90.50, with $t(33) = -32.012$, $p < 0.001$, Cohen's $d_z = 5.49$, and a mean N-Gain of 0.78. The findings indicated substantial pre-post improvement in learning outcomes within the studied group. However, because the study did not include a control group, the observed changes should not be interpreted as evidence of an isolated causal effect of the video tutorials.

Informasi Artikel

Kata Kunci:

CAM;
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ABSTRAK

Pembelajaran *Computer-Aided Manufacturing* (CAM) di sekolah menengah kejuruan masih banyak mengandalkan penjelasan lisan dan bahan ajar tertulis, padahal materi CAM bersifat prosedural, visual, dan membutuhkan demonstrasi langkah kerja secara bertahap. Penelitian ini menganalisis perubahan hasil belajar siswa kelas XI Teknik Pemesinan SMK Negeri 1 Singosari sebelum dan sesudah pembelajaran menggunakan video tutorial desain dan simulasi CAM. Penelitian menggunakan pendekatan kuantitatif dengan desain pre-eksperimental tipe *one-group pretest-posttest* yang melibatkan 34 siswa melalui teknik *total sampling*. Perlakuan dilaksanakan selama lima pertemuan menggunakan video tutorial yang mencakup pembuatan desain, pemilihan pahat dan material, pengaturan parameter pemesinan, pembuatan *toolpath*, simulasi, dan verifikasi proses CAM. Instrumen penelitian terdiri atas tes praktik, rubrik penilaian analitik, dan kuesioner skala Likert. Validitas isi diuji melalui *expert judgment* menggunakan Aiken's V dengan nilai rata-rata 0,948. Data dianalisis menggunakan statistik deskriptif, uji Shapiro-Wilk, *paired-samples t-test*, Cohen's d_z , dan N-Gain. Nilai rata-rata meningkat dari 57,09 menjadi 90,50, dengan $t(33) = -32,012$, $p < 0,001$, Cohen's $d_z = 5,49$, dan rata-rata N-Gain sebesar 0,78. Temuan menunjukkan adanya peningkatan hasil belajar sebelum dan sesudah intervensi pada kelompok yang diteliti. Namun, karena penelitian tidak menggunakan kelompok kontrol, perubahan yang diamati tidak dapat diinterpretasikan sebagai bukti efek kausal yang terisolasi dari penggunaan video tutorial.

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✉ **Corresponding Author:** (1) Prido Subekhi, (2) Department of Mechanical and Industrial Engineering, (3) Universitas Negeri Malang, (4) Malang, East Java, Indonesia, (5) Email: saifuddin.karim.ft@um.ac.id

1. Introduction

The development of digital manufacturing technologies has significantly changed the competencies required of the industrial workforce, particularly in machining based on Computer-Aided Manufacturing (CAM). Modern manufacturing industries require vocational education graduates not only to understand basic machining concepts but also to be able to perform design, parameter setting, simulation, and computer-assisted verification of production processes. In manufacturing, CNC/CAM learning is highly relevant to industry needs because these competencies are directly related to graduates' readiness to respond to technological developments in the Industry 4.0 era [1]. The use of interactive simulation and modeling software has also been shown to be an important means of equipping vocational students to master complex automated manufacturing programming workflows [2]. Therefore, CAM learning in vocational high schools needs to be supported by instructional media that can present work procedures visually, systematically, and contextually so that students can understand programming and machining simulation stages more effectively.

However, the implementation of CAM learning in vocational high schools still faces several challenges, including among Grade XI Machining Engineering students at SMK Negeri 1 Singosari. Based on preliminary observations during the learning process, students still experienced difficulty understanding the CAM workflow, particularly in creating designs, setting machining parameters, developing toolpaths, simulating cutting processes, and verifying results. These difficulties were also reflected in the initial pretest results, which showed a mean score of 57.09, below the school's established mastery criterion. This condition indicates that students' initial understanding of CAM was still limited and required instructional media capable of visualizing the work stages more clearly, sequentially, and in a form that could be reviewed repeatedly. Learning that is still dominated by lectures, limited demonstrations, and conventional media may make it difficult for students to understand procedural and visual content. [3] emphasized that CAM learning in vocational education should be aligned with industry needs so that students' competencies match workplace demands, particularly in problem solving, adaptability, and mastery of digital manufacturing technologies.

One instructional medium that is relevant to addressing these challenges is the video tutorial. Video tutorials can present work procedures audiovisually, help students observe processes in a clear sequence, and allow learning materials to be reviewed repeatedly according to individual learning needs. In vocational education, video can help bridge the gap between theoretical explanations and practice because procedural work processes can be presented more concretely. This is consistent with the findings of [4], who showed that the use of video tutorials in the Basic Mechanical Engineering Work subject at SMK Negeri 1 Bukittinggi improved student learning outcomes compared with conventional instructional media.

The use of video tutorials in mechanical engineering and machining instruction has also been reported to have a positive effect on student learning outcomes. [5] developed short video tutorials for basic turning instruction in vocational high schools and found that the media improved students' understanding and cognitive abilities in lathe operation. Similarly, [6] demonstrated that video tutorial-based instructional media had a significant effect on the learning outcomes of Grade XI students in the Turning Machining subject, with the experimental class

achieving higher outcomes than the control class.

In machining and CNC/CAM instruction, the need for visual learning media becomes increasingly important because the content is directly related to software operating procedures, machining simulation, and technical skills that require accuracy. The importance of visual media was also evident in CAM learning among Grade XI Machining Engineering students at SMK Negeri 1 Singosari. Preliminary observations indicated that some students still depended on direct teacher explanations when following the stages of CAM software operation. Students tended to experience difficulties when independently repeating design steps, parameter settings, toolpath simulation, and result verification. Interviews with the subject teacher also indicated that the instructional media being used did not yet fully support students in reviewing practical procedures outside class hours. This condition was reinforced by the initial pretest mean of 57.09, indicating that students' initial understanding of CAM content was not yet optimal. These findings demonstrate the need for instructional media that present CAM procedures sequentially and visually and that can be accessed repeatedly by students.

These findings are consistent with several previous studies. [7] developed CNC/CAM video tutorials for learning in the Machining Engineering department of vocational high schools and reported that the media were suitable for use based on expert validation. This finding was reinforced by [8], who developed case method-based CAM video tutorials for CAD/CAM instruction and obtained material expert validity of 87% and media expert validity of 89%, indicating that the media were highly valid and practical for instructional use. Beyond media development and validation, it is also important to measure the effectiveness of video tutorials in improving learning outcomes. [9] demonstrated that video tutorials on the functions of welding machine components in vocational high schools were effective in improving student learning outcomes based on N-Gain analysis. [10] also found that YouTube video tutorial-based instructional media for SMAW welding practice improved vocational students' learning outcomes using a pretest-posttest control group design and N-Gain analysis, with the experimental class achieving higher outcomes than the control class.

A review of previous studies reveals a research gap that warrants further investigation. Studies [7] and [8] contributed to the development of CNC/CAM video tutorials, but their primary focus was on media feasibility and validity based on expert assessment, and therefore they did not directly demonstrate the impact of the media on student learning outcomes. Meanwhile, studies [9] and [10] measured the effectiveness of video tutorials on learning outcomes, but the content was largely related to welding practice or other mechanical engineering topics rather than CAM design and simulation, which involve software-based procedural stages. Thus, relatively few studies have specifically examined the use of CAM design and simulation video tutorials in vocational high schools using N-Gain as an indicator of learning improvement together with a paired-samples t-test to test statistical significance. This gap is important because CAM instructional media should not only be theoretically feasible or valid according to experts, but should also be empirically evaluated in relation to changes in student learning outcomes.

Based on these issues, this study aimed to analyze pre-post changes in the learning outcomes of Grade XI Machining Engineering students at SMK Negeri 1 Singosari following instruction using CAM design and simulation video tutorials. The study is expected to contribute to the development of innovative instructional media in vocational education,

particularly in supporting more effective CAM learning and preparing students with competencies relevant to the needs of modern manufacturing industries.

2. Literature Review

Instructional media are tools used to convey learning materials, messages, or information so that the learning process becomes more effective, focused, and easier for students to understand. In vocational education, instructional media play an important role because the content is not only conceptual but also procedural and practice-oriented. Appropriate media can help students understand work sequences, observe processes, and connect theoretical knowledge with practical skills.

Video tutorials are a form of audiovisual instructional media that present content through a combination of moving images, text, audio, and step-by-step demonstrations. This medium is well suited to machining instruction because it can present work procedures sequentially and concretely. In CAM learning, video tutorials allow students to repeatedly observe design stages, machining parameter settings, toolpath development, simulation, and result verification, enabling them to learn at a pace that matches their individual level of understanding.

Theoretically, the use of video tutorials can be explained through multimedia learning theory. Multimedia learning theory proposes that learning can be more effective when information is presented through a combination of visual and verbal elements because both support information processing through more than one cognitive channel. In CAM learning, presenting content through video tutorials can reduce students' difficulty in understanding complex digital procedures because each work step is displayed visually while being explained verbally. Thus, video tutorials have the potential to help students construct a more integrated understanding of CAM design and simulation.

Learning outcomes refer to the abilities demonstrated by students after participating in the learning process. In this study, learning outcomes were operationalized through students' practical performance in completing CAM design and simulation tasks. The assessment covered procedural competence, accuracy of the resulting design and simulation, appropriate selection of machining parameters, toolpath and cutting tools, and task completion time. Improvement in learning outcomes was measured by comparing pretest and posttest scores and was subsequently analyzed using a paired-samples t-test and N-Gain.

Based on this theoretical foundation, the use of video tutorials in CAM learning is well supported because the characteristics of audiovisual media correspond to the procedural learning needs of vocational education. Studies on video tutorials in vocational learning indicate that video-based media can make an important contribution to students' understanding of procedural and practice-oriented content. [4] showed that video tutorials in the Basic Mechanical Engineering Work subject could increase learning interest, improve learning efficiency, and facilitate teachers' delivery of instructional content. Similar findings were reported by [5] and [6], who demonstrated that video tutorials improved students' understanding and learning outcomes in basic turning and Turning Machining. These findings suggest that video tutorials are relevant to machining instruction because they can transform complex practical procedures into more concrete and observable learning experiences.

In CNC/CAM learning, the need for video tutorials is more specific because the content involves not only physical

machining practice but also software-based digital procedures. The use of simulation software with graphical interfaces has been shown to effectively guide vocational students' understanding of computer-assisted machine control and programming steps in a gradual manner [11]. [7] developed CNC/CAM video tutorials for Machining Engineering instruction in vocational high schools and found that the media were valid and suitable for use based on expert assessment. [8] also developed case method-based CAM video tutorials for CAD/CAM learning and obtained high validity ratings from both material and media experts. Together, these studies support the feasibility of video tutorials as CNC/CAM instructional media. However, their focus remained largely on media development and validation, and therefore they did not fully demonstrate the extent to which video tutorial use was associated with empirical changes in student learning outcomes.

Compared with studies on other machining topics, research on the effectiveness of video tutorials for learning outcomes is more extensive. Studies [4], [5], and [6] consistently reported positive effects of video tutorials on vocational students' understanding and learning outcomes. However, the content examined in those studies focused on basic mechanical engineering work and turning. CAM design and simulation differ because students are required to understand a digital workflow involving design, parameter setting, toolpath development, simulation, and result verification. Consequently, the effectiveness of video tutorials in conventional machining instruction cannot be directly generalized to CAM learning, which relies more heavily on software operation and virtual process visualization.

Based on this synthesis, previous studies show two main trends. First, studies of video tutorials in mechanical engineering education generally report positive effects on learning outcomes, but rarely address CAM design and simulation specifically. Second, studies of CNC/CAM video tutorials have demonstrated media feasibility, but have largely been limited to development and validation. This study therefore occupies the intersection of these two research directions by empirically examining changes in vocational students' learning outcomes before and after the use of CAM design and simulation video tutorials through pretest-posttest comparison, a paired-samples t-test, and N-Gain analysis.

The novelty of this study lies in the empirical evaluation of video tutorials specifically designed to visualize CAM design and simulation procedures for vocational high school students. The novelty is not limited to the use of video tutorials themselves, but also concerns the context of CAM content, which is digital, visual, and procedural. Accordingly, this study extends research on video tutorials in vocational education from conventional machining instruction to software-based CAM learning. It also provides empirical evidence that instructional media should be evaluated not only in terms of feasibility or validity, but also in relation to changes in student learning outcomes.

3. Research Methods

This study employed a quantitative approach with a pre-experimental one-group pretest-posttest design [12]. The design was used to analyze changes in students' learning outcomes before and after instruction using CAM design and simulation video tutorials. Measurements were conducted through a pretest administered before the intervention and a posttest administered after all learning activities had been completed. Because the

study did not include a control group, the observed score changes cannot be interpreted as evidence that the video tutorials were the sole cause of the improvement in learning outcomes. The design remains susceptible to threats to internal validity, particularly history, maturation, testing effects, and possible Hawthorne effects [12]. Several procedural steps were applied to reduce some of these threats. The study was conducted within a relatively short period of five meetings in the same class and CAM learning context to limit the opportunity for major history and maturation effects. In addition, the pretest and posttest used different technical drawings while assessing the same competency indicators with the same scoring rubric and weighting scheme, thereby reducing direct task-repetition effects. However, no specific procedure was implemented to control possible Hawthorne effects. Therefore, these threats to internal validity could not be completely eliminated, and the findings were interpreted as pre-post changes within a single intervention group rather than as evidence of an isolated causal effect of the video tutorials.

The participants were 34 Grade XI Machining Engineering students at SMK Negeri 1 Singosari. Total sampling was used, meaning that all members of the population were included as research participants. The study was conducted over five meetings, each lasting approximately 240 minutes, in accordance with the school's CAM practical learning schedule.

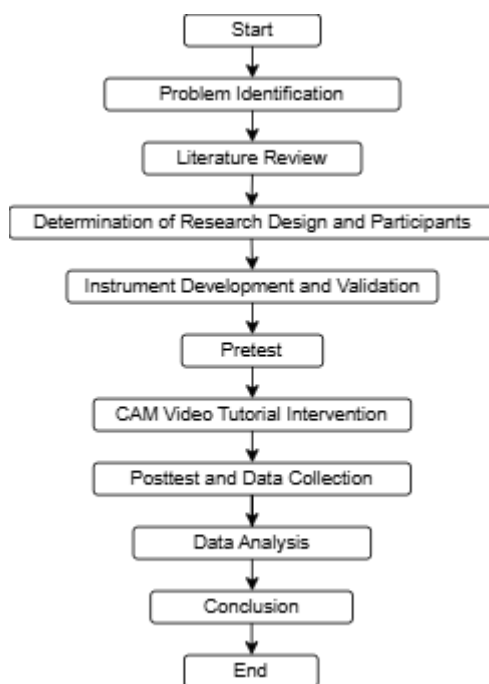


Figure 1 Research Flow Diagram

The research stages included problem identification and literature review, determination of the research design and participants, instrument development and validation, pretest

administration, implementation of the CAM video tutorial intervention, posttest administration, data analysis, and conclusion drawing. The research procedure is presented in Figure 1.

The study consisted of three main stages: pretest, intervention, and posttest. At the initial stage, students completed a practical pretest to measure their baseline ability in CAM design and simulation. Students were given a technical drawing to complete using Mastercam through a sequence of procedures that included preparing the software, setting the workpiece, creating the design, selecting the toolpath and cutting tool, setting machining parameters, and simulating the machining process.

The next stage involved instruction using CAM design and simulation video tutorials. A video was prepared for each meeting in accordance with the content and practical activities scheduled for that session. The video durations for Meetings 1 through 5 were 25, 37, 50, 30, and 20 minutes, respectively. Each video focused on a specific stage of the CAM workflow, including software introduction, workpiece design, material and cutting tool selection, machining parameter setting, toolpath generation, machining simulation, and result verification. The tutorials were accompanied by voice-over explanations delivered directly by the instructor while demonstrating each procedure. Zoom and highlighting features were used to emphasize important menus, commands, and parameter settings, while the cursor was used as a visual pointer to direct students' attention to the specific steps being demonstrated. The procedures were presented gradually and sequentially so that students could follow each stage before proceeding to the next. The organization of the video content was aligned with the practical tasks conducted during the same meeting, allowing students to directly apply the demonstrated procedures.

The video tutorials were accessed individually by students using their own smartphones during each meeting. The video platform allowed students to pause, replay, and review specific segments according to their learning needs, without restrictions on the number of repetitions. Students could also access the videos independently outside class hours as learning materials at home. However, access logs, viewing frequency, and the number of repetitions made by individual students were not formally monitored or recorded. Consequently, variation in individual exposure to the video tutorials could not be quantified, which represents a limitation in implementation fidelity.

After all learning activities had been completed, students took a practical posttest that assessed the same competency indicators as the pretest. The pretest and posttest used the same analytical rubric, aspect weightings, score ranges, and scoring procedures. The technical drawings used in the pretest and posttest were intentionally different to avoid repetition of the same task, but both assessed the same CAM competencies, indicators, and procedural stages. Thus, the two tasks were parallel in terms of the competency construct and scoring system, although the task forms were not identical.

The correspondence among video content, duration, and learning activities for each meeting is presented in Table 1.

Table 1 Implementation Stages of CAM Video Tutorial-Based Learning

Meeting	Video Tutorial Content	Duration	Learning Activities
1	Introduction to basic CAM concepts and the Mastercam software interface	25 minutes	The pretest was administered first, followed by an introduction to basic CAM concepts and the Mastercam software interface using the video tutorial.
2	Workpiece design creation	37 minutes	Students learned and practiced creating workpiece designs using the CAM video tutorial.
3	Material and cutting tool selection and machining parameter settings	50 minutes	Students learned and practiced material selection, cutting tool selection, and machining parameter settings.
4	Toolpath generation, machining process simulation, and error checking	30 minutes	Students generated toolpaths, conducted machining simulations, and checked for potential process errors.
5	Simulation result verification and reinforcement of CAM procedures	20 minutes	Students verified simulation results, completed independent practice and discussion, and then took the posttest.

The research instruments consisted of a pretest-posttest practical test, an analytical scoring rubric, and a student response questionnaire. Each pretest and posttest consisted of one practical CAM task based on a technical drawing that students were required to complete using Mastercam. The assessment blueprint covered three main components: the work process, the quality of the resulting CAM design and simulation, and task completion time. The process component assessed software preparation, workpiece setup, procedural accuracy, discipline, and work neatness. The result component assessed geometric and dimensional accuracy, conformity with the job sheet, selection of toolpath and cutting tools, machining parameters, simulation accuracy, and conformity of the final simulation result. The time component assessed whether the task was completed within the specified duration. The three components were weighted at 20%, 70%, and 10%, respectively. An example task required students to reproduce a technical drawing in Mastercam, define the workpiece and machining parameters, generate the appropriate toolpath, and perform a machining simulation until the required result was obtained. The student response questionnaire used a Likert scale to obtain data on students' perceptions of ease of use, clarity of content, the usefulness of the video tutorials, and their support for independent learning. The questionnaire used a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). For descriptive interpretation, mean scores were classified into five equal intervals: 1.00–1.80 as very negative, 1.81–2.60 as negative, 2.61–3.40 as neutral, 3.41–4.20 as positive, and 4.21–5.00 as very positive. The student response questionnaire was administered after the completion of the learning intervention.

Before being used in the study, the pretest-posttest practical test was validated through expert judgment by two validators: the academic supervisor and the CNC subject teacher at SMK Negeri 1 Singosari. Validation covered content, construction, and language aspects. The content aspect included the alignment of the instrument with learning outcomes, learning objectives, CAM design competence, CAM simulation competence, and

students' procedural abilities. The construction aspect included the clarity of instructions, clarity of the technical drawing, level of difficulty, and suitability of the instrument for pretest-posttest use. The language aspect covered sentence clarity, the absence of ambiguous wording, and suitability of the language for vocational high school students.

Content validity was formally evaluated using Aiken's V index [13]. The 12 indicators obtained Aiken's V values ranging from 0.875 to 1.000, with a mean of 0.948, indicating strong content validity. A separate construct-validity analysis was not conducted. Therefore, the validity evidence for the practical performance assessment in this study was limited to expert-based content validity using Aiken's V. Feedback from the validators was used to refine task instructions, improve the clarity of the technical drawings, and strengthen the assessment indicators. The practical assessment was conducted using the same analytical rubric, assessment criteria, weighting scheme, and scoring procedures for all students. The researcher and the CNC subject teacher participated in the assessment process; however, only the researcher's individual scoring data were available for the dataset analyzed in this study. Consequently, a numerical inter-rater reliability coefficient, such as Cohen's kappa or percentage agreement, could not be calculated. The absence of a formal inter-rater reliability coefficient is acknowledged as a methodological limitation of this study. No internal-consistency coefficient, such as Cronbach's alpha or KR-20, was calculated for the practical performance assessment.

Data were analyzed using descriptive and inferential statistics with IBM SPSS Statistics. Descriptive analysis was used to summarize the mean, standard deviation, minimum, and maximum pretest and posttest scores. Before hypothesis testing, the normality assumption for the paired-samples t-test was examined using the Shapiro-Wilk test on the difference scores between the pretest and posttest. Differences in learning outcomes before and after the intervention were then analyzed using a paired-samples t-test at a 5% significance level.

The magnitude of the change between pretest and posttest

scores was assessed using Cohen's d_z for paired data. Cohen's d_z was selected because the measurements were obtained from the same participants before and after the intervention [14]. Improvement in learning outcomes was also analyzed using normalized gain (N-Gain). N-Gain values were classified as high when $g \geq 0.70$, moderate when $0.30 \leq g < 0.70$, and low when $g < 0.30$, based on Hake's criteria [15].

4. Results

The study involved 34 Grade XI Machining Engineering students at SMK Negeri 1 Singosari. Learning outcomes were analyzed using descriptive statistics, a paired-samples t-test, effect size calculation, and normalized gain (N-Gain). Descriptive statistics for the pretest and posttest scores are presented in Table 2.

Table 2 Descriptive Statistics of Pretest and Posttest Scores

Measurement	N	Minimum	Maximum	Mean	Std. Deviation
Pretest	34	45	68	57.09	6.384
Posttest	34	88	95	90.50	1.762
Valid N (listwise)	34				

As shown in Table 2, the mean pretest score was 57.09, with a minimum of 45, a maximum of 68, and a standard deviation of 6.384. After instruction using CAM design and simulation video tutorials, the mean posttest score was 90.50, with a minimum of 88, a maximum of 95, and a standard deviation of 1.762. The mean difference of 33.41 points indicates a change in scores between the pretest and posttest measurements. Descriptively, the decrease in standard deviation from 6.384 to 1.762 indicates that posttest scores were more narrowly distributed than pretest scores. However, this narrowing was not interpreted as evidence that the magnitude of improvement was the same for all students, particularly because the posttest scores were concentrated within the range of 88-95 on a 0-100 scale, indicating a possible ceiling effect.

Analysis of individual score changes showed that all 34 students obtained higher posttest scores than pretest scores. Individual increases ranged from 22 to 46 points, with a mean change of 33.41 points and a standard deviation of 6.086. Thus, no student experienced a decrease or obtained the same score on the pretest and posttest. Interquartile range (IQR) analysis of the difference scores yielded a first quartile of 29.00 and a third quartile of 35.75, resulting in an IQR of 6.75. Using the $1.5 \times \text{IQR}$ criterion, one change score of 46 points was identified as an upper outlier. This outlier still represented a positive change and did not alter the overall pattern in which all students showed higher posttest scores.

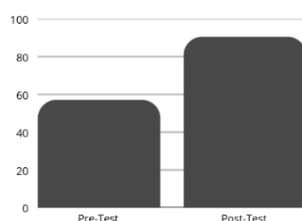


Figure 2 Comparison of Mean Pretest and Posttest Scores

Figure 2 shows the increase in the mean learning outcome score after students participated in instruction using CAM design and simulation video tutorials. The mean score increased by 33.41 points, from 57.09 on the pretest to 90.50 on the posttest. The visualization highlights the change in learning outcomes between the measurements before and after the intervention.

Before conducting the paired-samples t-test, the normality of the pretest-posttest difference scores was examined using the Shapiro-Wilk test. The results are presented in Table 3.

Table 3 Normality Test of Pretest–Posttest Difference Scores

Variable	N	Shapiro–Wilk (W)	p-value	Interpretation
Pretest–posttest difference scores	34	0.941	0.064	Normally distributed

As shown in Table 3, the Shapiro-Wilk test of the pretest-posttest difference scores yielded $W = 0.941$ and $p = 0.064$. Because $p > 0.05$, the difference scores did not significantly deviate from a normal distribution. Therefore, the normality assumption for the paired-samples t-test was satisfied.

A paired-samples t-test was subsequently conducted to determine whether there was a statistically significant difference in students' learning outcomes between the measurements before and after instruction using the video tutorials. This test was appropriate because the two sets of scores were obtained from the same participants at two different measurement times. The results are presented in Table 4.

Table 4 Results of the Paired-Samples t-Test

Comparison	Mean Difference	SD Difference	Std. Error Mean	95% CI Lower	95% CI Upper	t	df	p
Pretest–	-33.412	6.086	1.044	-35.535	-31.288	-32.012	33	< 0.001

Posttest

As shown in Table 4, the paired-samples t-test indicated a statistically significant difference between the pretest and posttest scores, $t(33) = -32.012$, $p < 0.001$. The mean difference of -33.412 indicates that the mean posttest score was higher than the mean pretest score. The negative sign results from calculating the difference as pretest minus posttest. The 95% confidence interval for the mean difference ranged from -35.535 to -31.288 and did not include zero. These results indicate a statistically significant change in scores between the measurements before and after the intervention.

$$d_z = \frac{\bar{D}}{SD_D} \quad (1)$$

$$g = \frac{S_{post} - S_{pre}}{S_{max} - S_{pre}} \quad (2)$$

The magnitude of the change between the pretest and posttest scores was quantified using Cohen's d_z for paired data. The mean difference of 33.412 was divided by the standard deviation of the difference scores, 6.086, resulting in $d_z = 5.49$. According to conventional effect-size interpretations, this value was very large. However, it should be interpreted in the context of the score distribution. The posttest scores were concentrated within a relatively narrow range of 88–95 on a 0–100 scale, indicating a possible ceiling effect. Therefore, the large effect size reflects the magnitude of score change in the group studied and should not be interpreted as evidence that the change was caused exclusively by the video tutorials or that the practical magnitude of improvement was identical for all students.

Improvement in learning outcomes was further analyzed using N-Gain. This analysis was used to determine the degree of improvement while accounting for students' initial scores and the maximum score that could be achieved. The distribution of students across N-Gain categories is presented in Table 5.

Table 5 Distribution of Students Based on N-Gain Categories

N-Gain Category	Range	Number of Students	Percentage
High	$g \geq 0.70$	33	97.1%
Moderate	$0.30 \leq g < 0.70$	1	2.9%

5. Discussion

The findings show that posttest learning outcome scores were higher than pretest scores after the implementation of CAM design and simulation video tutorial-based instruction among Grade XI Machining Engineering students at SMK Negeri 1 Singosari. Because this study used a one-group pretest-posttest design without a control group, this improvement represents a pre-post change within the studied group and should not be interpreted as evidence of an isolated causal effect of the video tutorials. The mean score increased from 57.09 on the pretest to 90.50 on the posttest. The paired-samples t-test also indicated a statistically significant difference between learning outcomes before and after the intervention. In addition, the mean N-Gain was 0.78, which was classified as high, with 33 students (97.1%) in the high category and one student (2.9%) in the moderate category. The consistency among the change in mean scores, the statistical test, the effect size, and the N-Gain indicates a substantial change in learning outcomes after students participated in instruction using the video tutorials.

The high N-Gain can be considered in relation to the

Low	$g < 0.30$	0	0%
Mean N-Gain	0.78		

As shown in Table 5, 33 students (97.1%) obtained N-Gain scores in the high category, while one student (2.9%) was classified in the moderate category. No students were classified in the low category. The mean N-Gain of 0.78 was classified as high according to Hake's criteria [15]. However, these results should be interpreted alongside the characteristics of the posttest score distribution, which was concentrated within the relatively narrow range of 88–95 out of a maximum score of 100. This pattern suggests a possible ceiling effect; therefore, the N-Gain value was not interpreted in isolation as the sole indicator of improvement in learning outcomes.

Students' responses to the CAM video tutorials were also analyzed descriptively using a Likert-scale questionnaire. The questionnaire assessed four aspects: ease of use, clarity of content, usefulness of the video tutorials, and support for independent learning. The results are presented in Table 6.

Table 6 Student Responses to the CAM Video Tutorials

Indicator	Mean Score	Interpretation
Ease of use	4.44	Very positive
Clarity of content	4.44	Very positive
Usefulness of the video tutorials	4.65	Very positive
Support for independent learning	4.59	Very positive
Overall mean	4.53	Very positive

As shown in Table 6, students generally provided very positive responses to the CAM video tutorials. The highest mean score was obtained for the usefulness of the video tutorials ($M = 4.65$), followed by support for independent learning ($M = 4.59$). Ease of use and clarity of content each obtained a mean score of 4.44. The overall mean score was 4.53, indicating that students responded very positively to the use of CAM video tutorials as supporting media for CAM learning.

characteristics of both the instructional medium and the learning content. CAM design and simulation involve a complex and sequential structure that includes creating a design, setting the material and workpiece zero point, selecting cutting tools, setting machining parameters, developing toolpaths, simulating tool movement, and verifying results. An error at one stage may affect subsequent stages, so students need to understand the relationships among the processes as a whole. In this study, the video tutorials presented the complete workflow systematically rather than merely showing the final result. This sequential presentation allowed students to understand the relationships among design, machining parameters, toolpaths, and simulation results.

Unlike direct demonstrations, which are generally observed only while instruction is taking place, video tutorials can be paused, replayed, and reviewed according to students' needs. Students who do not fully understand a particular stage can repeat specific sections without waiting for the teacher to demonstrate the procedure again to the entire class. This feature allows students to adjust their learning pace, identify errors, and correct their work before proceeding to the next stage. This

mechanism may have contributed to the high N-Gain because students had more consistent opportunities to review and practice CAM procedures.

The high proportion of students in the high N-Gain category should be interpreted cautiously because the posttest scores were concentrated within the range of 88-95 out of a maximum score of 100. N-Gain measures improvement relative to the maximum possible improvement based on each student's initial score; consequently, the results are influenced by the pretest score, the maximum score used, and the category thresholds applied. Therefore, the proportion of students in the high N-Gain category was not treated as stand-alone evidence. The findings were interpreted together with the actual score differences, the distribution of individual scores, the paired-samples t-test, and the effect size. This study used one N-Gain formula and one set of category criteria specified in advance; the sensitivity of the results to alternative formulas or category thresholds was not specifically tested.

The mean N-Gain of 0.78 obtained in this study was comparable to findings from previous studies on video tutorial-based vocational learning. Azmi et al. [9] reported an N-Gain of 0.7670 in the experimental group using video tutorials on welding machine components, while Athar et al. [10] reported an N-Gain of 0.6100 in the experimental group using YouTube-based video tutorials for SMAW welding practice. Although the N-Gain in the present study was slightly higher, direct comparison should be made cautiously because the studies differed in learning content, assessment instruments, participants, and research design. Nevertheless, the findings consistently indicate substantial learning improvement following video-supported vocational instruction.

The standard deviation decreased from 6.384 on the pretest to 1.762 on the posttest. Descriptively, this indicates that posttest scores were more narrowly distributed than pretest scores. However, the reduction in standard deviation cannot be directly interpreted as evidence that the video tutorials produced uniform improvement across all students. Analysis of individual score changes showed that every student improved, but the magnitude of change varied from 22 to 46 points. In addition, the posttest scores were concentrated within the range of 88-95 on a maximum scale of 100, indicating a possible ceiling effect that may also have contributed to the narrower score distribution. Therefore, the change in standard deviation was used only to describe the score distribution and not as evidence of homogeneous learning effects.

Theoretically, the findings can be explained through the Cognitive Theory of Multimedia Learning [16]. This theory proposes that learning involves visual and verbal processing channels with limited capacity. Learning can be more effective when visual and verbal information is presented in an integrated and structured manner, reducing the need for students to allocate excessive cognitive capacity to connect information presented separately. In CAM learning, the video tutorials combined the software interface, cursor movements, parameter changes, explanatory text, and spoken narration. This combination helped students connect instructions with the actions being demonstrated directly on screen.

The use of video tutorials is also consistent with the segmentation principle of multimedia learning, in which complex content is divided into smaller units that can be processed gradually [17]. Complex CAM procedures were broken down into smaller stages so that students did not need to process the entire workflow simultaneously. Design, parameter setting, toolpath creation, simulation, and verification were

learned in stages. This segmentation may help reduce extraneous cognitive load and provide students with more capacity to process essential information. Thus, video tutorials function not only as a means of delivering information but also as procedural representations that can help students construct a mental model of the CAM workflow.

The findings are consistent with studies [4], [5], and [6], which reported that video tutorials made a positive contribution to students' understanding and learning outcomes in mechanical engineering. This similarity can be explained by the procedural nature of the learning content, which requires step-by-step demonstration. In machining instruction, conceptual explanations alone are insufficient; students also need to observe how procedures are performed in sequence. Video tutorials address this need by providing visual demonstrations that can be presented consistently and repeatedly.

However, an important distinction exists between this study and previous research. Study [4] focused on Basic Mechanical Engineering Work, while [5] and [6] examined basic turning and Turning Machining. Those topics involve conventional machining procedures and the physical operation of equipment. In contrast, the present study examined CAM design and simulation conducted within a software-based digital environment. Students needed to understand the relationships among design objects, cutting tool selection, cutting parameters, toolpath generation, and virtual simulation results. Therefore, this study extends previous findings on the use of video tutorials from conventional machining instruction to digital manufacturing learning with a more complex visual and procedural structure, consistent with the importance of interactive digital design media in vocational environments [2].

This study is also related to [8], who developed case method-based CAM video tutorials and reported high levels of validity and practicality. Both studies used video tutorials to support the visualization of software-based CAM processes. However, Febriansyah and Kurniawan focused primarily on media development and feasibility assessment in a higher education context. The present study was conducted with vocational high school students and examined changes in learning outcomes using a pretest, posttest, paired-samples t-test, N-Gain, and effect size. Thus, the previous study mainly demonstrated that CAM video tutorials were feasible and practical, whereas the present study adds empirical evidence regarding changes in learning outcomes after the media were implemented in secondary vocational education.

Differences in research design should also be considered when comparing the findings. Study [6] used a quasi-experimental design with experimental and control classes, providing a stronger basis for comparison with instruction that did not use video. In contrast, the present study used a one-group pretest-posttest design and compared conditions before and after the intervention within the same group. Accordingly, this study can demonstrate the magnitude of change in learning outcomes, but it does not provide the same strength of evidence for concluding that the change was caused solely by the video tutorials. This comparison indicates that the findings are consistent with previous studies, while the strength of the causal evidence differs.

The questionnaire results supported the quantitative learning outcome findings, with an overall mean response score of 4.53. Students gave the highest rating to the usefulness of the video tutorials ($M = 4.65$), followed by support for independent learning ($M = 4.59$), while ease of use and clarity of content each obtained a mean score of 4.44. Students' responses indicated that

the video tutorials were perceived as easy to use, clear in presenting the learning content, useful for supporting CAM practice, and supportive of independent learning. These responses are consistent with the characteristics of video, which allow students to review content and follow procedures at their own pace. However, questionnaire results represent perceptual data and therefore cannot serve as objective evidence on their own. The strength of the findings lies in the consistency among the practical test results, N-Gain, effect size, and student responses to the media.

The novelty of this study lies in the empirical evaluation of video tutorials that specifically present CAM design and simulation procedures at the vocational high school level. Previous research has generally followed two directions: studies examining the effectiveness of video tutorials in conventional machining and studies developing CNC/CAM video media with a greater emphasis on validity and practicality. The present study connects these two directions by examining changes in students' learning outcomes after the use of software-based CAM video tutorials. Its contribution lies not merely in the use of video as an instructional medium, but in providing empirical evidence of substantial changes in learning outcomes following the visual, systematic, and repeatable presentation of CAM procedures.

From a practical perspective, the findings indicate that video tutorials can be used as supporting media in CAM learning in vocational high schools. The videos can complement teacher demonstrations, serve as practical guides, and provide independent learning resources when students experience difficulties. Video use can also help maintain consistency in procedural explanations because all students receive the same sequence and content. For teachers, video tutorials may reduce the need to repeatedly demonstrate basic procedures, allowing more instructional time to be devoted to feedback and support for more specific student errors.

Despite the substantial improvement in learning outcomes, this study has several limitations. First, the one-group pretest-posttest design did not include a control group, so the observed improvement cannot be attributed exclusively to the video tutorials. Other factors, such as repeated practice, teacher interaction, previous learning experience, and classroom conditions, may also have contributed to the score changes. Second, the study involved only one class with 34 students; therefore, generalization to other schools or contexts should be made cautiously. Third, the high and relatively narrow range of posttest scores may indicate a ceiling effect, suggesting that the instrument may have had limited ability to distinguish among students at higher performance levels. In addition, formal inter-rater reliability could not be estimated because only the researcher's scoring data were retained for analysis. Although the same analytical rubric, assessment criteria, and scoring procedures were used during the assessment process, the absence of separate rater-level scores prevented the calculation of a numerical agreement coefficient. In addition, individual access to the video tutorials outside class hours was not formally monitored. Access logs, viewing frequency, and the number of repetitions were not recorded; therefore, differences in students' exposure to the video tutorials could not be quantified. This limitation should be considered when interpreting the fidelity of the intervention implementation.

Fourth, the study did not include a delayed posttest or follow-up assessment, so the retention of learning outcomes over time could not be evaluated. Fifth, the study relied primarily on quantitative data and did not include qualitative evidence, such as interviews or classroom observations, to explore how students

experienced the video tutorials or which features of the videos contributed most to their understanding. Future studies should use quasi-experimental designs with a comparison group, include samples from several schools, incorporate delayed posttests to examine learning retention, and combine quantitative and qualitative approaches to obtain a more comprehensive understanding of the learning process.

Overall, the use of CAM design and simulation video tutorials was associated with improved learning outcomes among Grade XI Machining Engineering students. The high N-Gain may be related to the systematic presentation of content, the integration of visual and verbal information, the division of procedures into smaller stages, and opportunities for students to repeat learning materials according to their needs. Although the present study cannot directly compare the video tutorials with other instructional methods because no control group was included, the findings suggest that video tutorials are worth considering as supporting media for CAM learning, which is inherently digital, visual, and procedural.

6. Conclusion

This study documented higher learning outcome scores after CAM design and simulation video tutorial-based instruction than before the intervention within a single group of Grade XI Machining Engineering students at SMK Negeri 1 Singosari. The improvement was reflected in the change between pretest and posttest scores, the paired-samples t-test, the effect size, and N-Gain. These findings represent pre-post improvement within the studied group and should not be interpreted as evidence of an isolated causal effect of the video tutorials. Because the study used a one-group pretest-posttest design without a control group, other factors occurring during the learning process may also have contributed to the observed changes.

Theoretically, the findings are consistent with the principles of multimedia learning, which emphasize the integration of visual and verbal elements to support the processing of procedural information. In the context of this study, the visual and structured presentation of CAM procedures may have supported students' understanding of design, parameter setting, toolpath development, simulation, and verification. However, this relationship cannot be interpreted as a fully causal relationship because other factors during the learning process may also have contributed to the changes in learning outcomes.

From a practical perspective, video tutorials can be considered supporting media for CAM learning in vocational high schools. They can complement teacher demonstrations, serve as practical guides, and provide independent learning resources because students can pause, replay, and revisit the material as needed. Although the findings show positive changes in learning outcomes, video tutorials should be understood as one component of the learning process rather than the sole factor determining improvement in learning outcomes.

Nevertheless, the findings should be interpreted cautiously because the one-group pretest-posttest design did not include a control group. Therefore, the study demonstrates only changes in learning outcomes before and after instruction using video tutorials within the same group and does not establish that the video tutorials were the sole cause of the improvement. Future research is recommended to use a quasi-experimental non-equivalent control group design, in which one group receives CAM instruction using video tutorials and a comparison group receives regular instruction without video tutorials. To maintain

comparability between groups, the learning content, learning objectives, instructional duration, software, practical tasks, and assessment rubric should be equivalent. The initial abilities of both groups should also be assessed through a pretest before the intervention, followed by a posttest using the same competency indicators. Such a design would provide a stronger basis for determining whether differences in learning outcomes can be attributed to the use of video tutorials rather than to other factors occurring during the learning process.

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